FUSER SYSTEM AND METHOD FOR LIQUID TONER ELECTOPHOTOGRAPHY USING MULTIPLE ROLLERS

Technical Field

The present invention relates fusing devices and systems for use with electrophotographic processes and particularly relates to the use of such devices and systems with liquid toner materials.

Background of the Invention

Electrophotography forms the technical basis for various well-known imaging processes, including photocopying and some forms of laser printing. One basic electrophotographic process involves placing a uniform electrostatic charge on a photoreceptor, and then exposing the photoreceptor to activating electromagnetic radiation in particular areas that correspond to an image to be printed or transferred. The electromagnetic radiation, which may also be referred to as "light", may include infrared radiation, visible light, and ultraviolet radiation, for example. This exposure of the photoreceptor to light dissipates the charge in the exposed areas to form an electrostatic latent image. The resulting electrostatic latent image is developed with a toner, and then the toner image is transferred from the photoreceptor to a final substrate, such as paper, either by direct transfer or via an intermediate transfer material. The direct or intermediate transfer of an image typically occurs by one of the following two methods: elastomeric assist (also referred to herein as "adhesive transfer") or electrostatic assist (also referred to herein as "electrostatic transfer"). Elastomeric assist or adhesive transfer refers generally to a process in which the transfer of an image is primarily caused by surface tension phenomena between a photoreceptor surface and a temporary carrier surface or medium for the toner. The effectiveness of such elastomeric assist or adhesive transfer is controlled by several variables including surface energy, temperature, pressure,

and toner rheology. Electrostatic assist or electrostatic transfer refers generally to a process in which transfer of an image is primarily affected by electrostatic charges or charge differential phenomena between the receptor surface and the temporary carrier surface or medium for the toner. Electrostatic transfer, like adhesive transfer, is controlled by surface energy, temperature, and pressure, but the primary driving forces causing the toner image to be transferred to the final substrate are electrostatic forces. After the toned image is transferred by either type of transfer method, electrophotographic processes may further include the processes of fusing the transferred image to the substrate, cleaning the photoreceptor, and erasing any residual charge on the photoreceptor to prepare the system for the transfer of a new image.

In some common electrophotographic processes, the structure of a photoreceptor is a continuous belt, which can be supported and circulated by rollers or a rotatable drum, for example. Photoreceptors generally have a photoconductive layer that transports charge (either by an electron transfer or charge transfer mechanism) when the photoconductive layer is exposed to activating electromagnetic radiation or light. The photoconductive layer is generally affixed to an electroconductive support, such as a conductive drum or a substrate that is vapor coated with aluminum or another conductor. The surface of the photoreceptor can be either negatively or positively charged so that when activating electromagnetic radiation strikes certain regions of the photoconductive layer, charge is conducted through the photoreceptor to neutralize, dissipate or reduce the surface potential in those activated regions. An optional barrier layer may be used over the photoconductive layer to protect the photoconductive layer and thereby extend the service life of the photoconductive layer. Other layers, such as adhesive layers, priming layers, or charge injection blocking layers are also used in some photoreceptors. A release layer may also be used to facilitate transfer of the image from the photoreceptor to either the final substrate, such as paper, or to an intermediate transfer element.

Typically, a toner image that corresponds to the electrostatic latent image on the photoreceptor may be formed by providing a positively charged toner that is attracted to those areas of the photoreceptor that retain a less positive charge after exposure to electromagnetic radiation. Two commonly available general types of toners are referred

to as dry toners and liquid toners. Dry toners will often be a powdered material comprising a blend or association of polymer and colored particulates, such as carbon for a black image, and liquid toners will often be a liquid material of finely divided solids dispersed in an insulating liquid that is frequently referred to as a carrier liquid. Generally, the carrier liquid may be a hydrocarbon that has a relatively low dielectric constant (e.g., less than 3) and a vapor pressure sufficiently high to ensure rapid evaporation of solvent following deposition of the toner onto a photoreceptor, transfer belt, and/or receptor sheet. Rapid evaporation is particularly important for cases in which multiple colors are sequentially deposited and/or transferred to form a single image.

Liquid toners can provide advantages over dry or powdered toners in certain applications because they are capable of producing higher resolution images while requiring lower energy for image fixing than dry toners. In addition, it is preferable for the toned image on the final substrate to be fixed to the substrate in such a way that it is resistant to removal in a variety of uses, abuses, and environmental conditions. However, the ink of the toned image that is deposited on the final substrate is often fragile and may not bear the attack of scratching or rubbing by outside forces such as human finger contact or such as erasure by a rubber pencil eraser, which may be referred to as poor "erasure resistance." Furthermore, transferred inks having residual tack or stickiness may also undesirably stick to other final substrates when placed in a stack, which can cause image damage when adjacent substrates are separated from one another when a portion of the image peels away from the transferred image and onto another surface. This tendency of the image to undesirably transfer from one substrate to an adjacent substrate may be referred to as poor "blocking resistance."

In order to render the inks to be adequately resistant to external forces such as blocking and erasure, it is sometimes desirable to heat the ink to an elevated temperature by contacting the surface of the final substrate to which the ink has been transferred with heat, such as a heated roll. Examples of fuser configurations having a single heated roller with at least one non-heated pressure roller for pressing a toned image toward the heated roller can be found in U.S. Patent Nos. 4,806,097 (Palm et al.), 5,893,019 (Yoda et al.), and 5,897,294 (Yoda et al.). This process is commonly referred to as "fusing" and is

often achieved by subjecting the final paper print to a heat source immediately after the transfer of ink to paper or another substrate. In the case of liquid toners, the use of heat can facilitate fixation of the ink by causing evaporation of the liquid portion of the toner. The heat also can serve to melt the toner particles onto the final substrate for permanence and durability.

Many types of heat sources may be used to fuse inks to paper or other mediums, such as a heated belt, a heated drum, or heated air, for example. Because some toners melt at different temperatures than others, the temperature necessary to adequately fuse the toner particles is usually customized to the chemical properties of the toner. If the temperature of the heating roller or element is too high, the toner may stick to the roller or other element and then be transferred back to the final substrate on a subsequent revolution of a roll, for example. This problem is known as "hot offset" and can often be cured by lowering the temperature of the roller. If the temperature of the heating roller or element is too cool, however, the toner particles may fail to fuse to the final substrate, and may also transfer to the roller or element, and possibly to the final substrate on a subsequent revolution, which may be referred to as "cold offset." Thus, to achieve a proper transfer of toner in such a way that the ink can adequately bond to the final substrate, the heater roller or element should desirably be maintained at a relatively constant temperature within a defined range. This may be difficult to achieve, however, with certain types of heating systems.

Fusing images made with liquid toners thus presents special challenges as compared to the fusing of images created using other toner materials. First, the constant contact of liquid toner with a heated roller or element essentially creates a constant cooling "bath," which may make it more difficult to maintain an adequate and relatively constant temperature for both eliminating the carrier liquid and fusing the image. Second, many of the devices and low surface energy materials used for dry toner fusing are not formulated to be used in a system where liquid or steam can penetrate, pool, run, or be imbibed, as is sometimes the case in electrophotographic systems using liquid toners. Third, traditional fusing, which is often used for dry toner systems where the final substrate is heated with the image facing the heating element, may not allow a sufficient

amount of the evaporated carrier liquid to move away from the heating element, which may cause the carrier to undesirably re-condense on the final substrate and other components of the printing device. It is therefore desirable to provide devices, systems, and methods of fusing liquid toners that provide consistent, high quality images on a final substrate.

Summary of the Invention

In one aspect of this invention, a fusing apparatus is provided for fixing images made from a liquid toner onto a substrate using an electrophotographic process. The apparatus includes a prefusing roller, a backup roller positioned to create a first nip area between the prefusing roller and the backup roller, and a fusing roller positioned to create a second nip area between the fusing roller and the backup roller. The prefusing roller, the backup roller, or both rollers are heated to a temperature that provides a prefusing temperature within the first nip area. Further, the fusing roller, the backup roller, or both rollers are heated to a temperature that provides a fusing temperature in the second nip area that is different than the prefusing temperature of the first nip area. In one preferred embodiment, the fusing temperature is higher than the prefusing temperature.

The fusing apparatus may be included within an electrophotographic printing device, wherein the first nip area between the prefusing roller and backup roller is positioned within the printing device to contact an image on a substrate prior to the second nip area between the fusing roller and backup roller contacting the image on the substrate. At least one of the prefusing roller and the backup roller may be maintained at a temperature between about 100°C and about 150°C, and at least one of the first and fusing roller and the backup roller may be maintained at a temperature between about 130°C and 220°C.

In another aspect of the invention, a method of fixing images made from a liquid toner onto a substrate within an electrophotographic printing device is provided. The method includes the steps of placing a liquid toned image on at least one surface of a substrate, moving the substrate through a first nip area of a fusing apparatus of the printing device, the first nip area being positioned between a prefusing roller and a

backup roller, and moving the substrate through a second nip area of the fusing apparatus, the second nip area being positioned between a fusing roller and the backup roller. At least one of the prefusing roller and the backup roller is heated to a temperature that provides a prefusing temperature within the first nip area, and at least one of the fusing roller and the backup roller is heated to a temperature that provides a fusing temperature in the second nip area that is higher than the prefusing temperature of the first nip area.

Brief Description of the Drawings

The present invention will be further explained with reference to the appended Figures, wherein like structure is referred to by like numerals throughout the several views, and wherein:

Figure 1 is a side schematic view of a prior art fusing apparatus as is typically used in the dry toner art;

Figure 2 is a side schematic view of one embodiment of the fusing apparatus of the present invention; and

Figure 3 is a side schematic view of another embodiment of the fusing apparatus of the present invention.

Detailed Description of the Preferred Embodiments

Toner materials commonly used in electrophotography can be generally divided into the categories of dry toners and liquid toners. The term "dry" is not meant to refer to a toner that is totally free of any liquid constituents, but refers to toner particles that do not contain a significant amount of solvent. For typical dry toners, the amount of solvent would typically be less than 10 weight percent solvent, for example, and may be less than 8 weight percent solvent or even less than 5 weight percent solvent, where solvent content is preferably as low as is reasonably practical for a particularly dry toner. In contrast, a typical liquid toner composition of the type used in the methods and systems of the present invention generally includes toner particles that are suspended or dispersed in a carrier liquid. The carrier liquid is preferably a nonconductive dispersant liquid, where this lack of charge carrying capability is desirable to avoid discharging any latent

electrostatic images during the printing process. Liquid toner particles are preferably solvated or stabilized (i.e., dispersed and suspended) to some degree in the carrier liquid, typically in more than 50 weight percent by total weight of the toner, of a low polarity, low dielectric constant, substantially nonaqueous carrier solvent. The liquid toner particles are preferably chemically charged using polar groups that dissociate in the carrier solvent, but the toner particles preferably do not contain a triboelectric charge while solvated and/or dispersed in the carrier liquid. Because liquid toners often contain particles that are smaller in size than the particles in a dry toner, liquid toners of the type used in the present invention are often capable of producing toned images with a higher resolution than those produced by dry toners.

Referring now to the Figures, wherein the components are labeled with like numerals throughout the several Figures, and initially to Figure 1, a schematic view of one typical fuser apparatus 100 used in dry toner applications is illustrated, which generally includes a first roller 102, a second roller 106, and a substrate 114 moving in a direction generally shown by the arrow 103. The first roller 102 can be heated internally, such as by a heating element 104, which may be a halogen lamp, for example, although other heating elements may be used, including heating blankets and heating lamps. The backup roller 106 is positioned to be in contact with the first roller 102, thereby creating a contact nip 116 between the rollers 102 and 106 that is sufficiently loose to accommodate the thickness of substrate 114. In many cases, the backup roller 106 is also heated by a heating element 108 similar to that used with the first roller 102. At least one of the rollers is typically driven by a driving mechanism (not shown), and the rollers 102, 106 rotate as generally shown by arrows 110, 112, respectively. Substrate 114 with non-fused or toned images on one side is typically provided to the nip area 116 and conveyed through this nip area 116 in the direction 103 so that the combined heat from the rollers 102, 106 melts the toner, fusing it onto the substrate 114. The image (not shown) can face either of the rollers 102, 106 if both are heated, but typically faces the heated roller if only one of the rollers is heated.

In accordance with one preferred embodiment of the present invention, the fuser apparatus or system shown in Figure 2 accommodates the requirements of liquid toner

fusing by providing a way of "prefusing" a liquid toner prior to fixing or fusing the image to a substrate. In particular, the present invention provides an initial processing step for evaporating at least a portion of the carrier liquid at a temperature that is low enough to keep the toner from sticking or "offsetting", and at a temperature that is high enough to provide a desired amount of carrier liquid evaporation. This initial step can greatly enhance image quality and durability achieved on the substrate after at least one additional fusing step. As shown particularly in the embodiment of Figure 2, a fuser apparatus or system 10 is provided, which generally includes a prefusing roller 12, a fixing or final fusing roller 14, and a backup or compression roller 16. As shown in this figure, a substrate 24 is traveling in a direction shown by the arrow 26. In accordance with the invention, the substrate 24 will be provided to the system 10 with a non-fused or toned image formed by a liquid toner on at least one side of the substrate 24. The image will preferably be fused to the substrate 24 after passing through the system 10 using the methods and systems described below.

More specifically, the prefusing roller 12 is arranged relative to the backup roller 16 to evaporate at least an initial portion of a carrier liquid from a liquid toned image on the substrate 24. The rollers 12 and 16 are preferably positioned relative to each other in such a way to provide a nip area 32 between them. This nip area 32 is the area or region where the two rollers 12 and 16 are in contact with each other, which determines the length of time during which a moving substrate will contact the heated prefusing roller as it passes through the nip area (i.e. "dwell time"). Because the rollers 12 and 16 are preferably in contact across the entire lengths of both rollers, the size of the nip area is mainly controlled by adjusting the width of the contact area in the travel direction of the substrate. The size of the nip area 32 may be controlled, for example, by adjusting the hardness of one or more of the roller layers of either or both of the rollers, and/or by increasing or decreasing the force or pressure that is pressing the rollers 12 and 16 toward each other. For example, the size of the nip area 32 can be decreased by increasing the hardness or durometer of at least one of the rollers 12 and 16, and/or decreasing the pressure applied to the two rollers. These parameters and adjustments should preferably be chosen to accommodate the thickness and various other material properties of any

substrates that will pass through the nip area 32. For one example, although a relatively thin material may be able to pass through a relatively tight or high-pressure nip area, it is also important that the rollers are not pressed so hard toward each other that the substrate will tend to wrinkle or tear when passing through the nip area. In one preferred embodiment of the present invention, the nip width is in the range of 0.5 mm to 3 mm, with a more preferred range being 1.5 mm to 2.5 mm.

As described above, the amount of time the substrate 24 can spend in the nip area 32 may be at least partially controlled through selection of the durometer or hardness of the outer coating or rubber layers of the rollers 12 and 16, or the hardness of the rollers themselves if no coating layers are provided. The hardness of the coating layers (e.g., rubber layers with or without any overcoat or release layers) is important because if the roller is too soft, the coating may bend, which may cause cracking or delamination of the coating. In addition, the substrate to which the toner is being fused might also bend and distort if the hardness of the rollers is too low. If the rollers are relatively hard, the nip area 32 will be relatively small and the duration of time that heat may be applied to the toner and substrate will be reduced, which may result in insufficient fixation of the toner to the substrate and/or insufficient evaporation of solvent. Furthermore, a nip 32 that is provided between rollers that are too soft and/or have too wide of a nip area may tend to cause the final substrate to wrinkle and may trap evaporated solvent between the rollers 12 and 16. In contrast, a nip 32 that is provided between rollers that are too hard and/or have too narrow of a nip area may not provide enough dwell time between the rollers and the image to evaporate a sufficient amount of the solvent.

The hardness or durometer of each roller is determined by the cumulative hardness of all of the layers of materials (e.g., rubbers, silicones, release coatings, and the like) that make up the structure of that roller. While rollers that have a relatively low durometer are softer and therefore create a wider nip that allows for a longer period of time for substrate contact with the rollers, these rollers are often less durable and are therefore more likely to break down from heat and constant use. In contrast, a higher durometer roller will be harder and therefore create a narrower nip that provides a shorter time for substrate contact with the rollers. These harder rollers will, however, typically be more able to withstand

heat for longer periods of use. Thus, rollers are preferably selected to balance the need for a certain nip width for fusing performance with the desired time that a particular roller can be used before being replaced. The overall hardness of the coating layers on the rollers is preferably in a range between 5 and 50 Shore A hardness, but more preferably is in a range between 10 and 30 Shore A hardness. The rollers 12 and 16 may have the same hardness, or the rollers may differ from each other in hardness.

The rollers 12 and 16 may be made by a wide variety of manufacturers, including rollers commercially available from Bando USA Inc. (Itasca, Illinois), Bando International (Chuo-Ku, Kobe, Japan), Minco Manufacturing (Colorado Springs, CO), and Ames Rubber Co. (Hamburg, N.J.). Several important characteristics that are preferably considered in the selection of rubbers used on fusing rollers include: the durability at a particular temperature, including scratch and solvent resistance for liquid electrophotography; the compliance for optimal nip residence time; and, in many cases, the ability to act as an adherent substrate for any sort of a release or low surface energy layer which may be applied. Examples of rubbers and compositions, along with parameters that may be considered in the selection thereof, are described, for example, in U.S. Patent Nos. 5,974,295 (De Neil, et al.) and 6,602,368 (Geiger). Coatings can be included on at least one of the fuser rollers such as rollers 12 and 16 to allow the toner particles to release easily from the surface, even after heating of the toner particles. Fluoroelastomers and polydimethyl siloxanes are two examples of coatings that may be used for such applications because of their low surface energies. For example, dimethyl siloxane tends to rapidly increase in surface energy at higher temperatures, which can thereby cause offset, and is therefore more effective at lower temperatures, as in the first fusing station 12. For another example, a fluorinated polymer such as Teflon® can be used without causing offset in fusing stations where the rollers are at a relatively high temperature and where the image to be fused is substantially dry, such as on the second or final fusing roller, as will be described in further detail below.

If a roll base is used without additional release coatings, the base rubber or material preferably has a low enough surface energy that the toner does not tend to stick to the base material when the substrate 24 exits the nip area 32 between rollers 12 and 16. Some

examples of rubbers and materials that can meet these requirements include fluoroplastomers, fluoroelastomers, polysiloxane elastomers, polyurethanes, and ethylene-propylene elastomers, where some of these materials are more effective than others at higher temperatures due to surface energy changes. Fillers may also be employed to enhance electrical or thermal conductivity, as in the case of fusing systems that heat to their operating temperature very rapidly (i.e., "instant on" applications). For one example, aluminum roller cores can be used, which cores can be coated with about 1-2 mm of silicone rubber having a hardness of 10 and 30 Shore A. The rubber can also be coated with about 0.025 mm to 0.050 mm of polydimethyl siloxane, for example, as a release coating.

Another factor used in designing a nip area 32 is the selection of a pressure with which the two rollers 12, 16 will press against one another and a substrate 24. The pressure to which the substrate 24 is subjected as it passes through the nip area 32 can affect the print quality. For instance, if there is insufficient pressure, the image may be smeared in the nip or an insufficient amount of solvent may evaporate. If there is too much pressure, the substrate 24 may be damaged or destroyed. In one embodiment of the invention, the pressure between the rollers is preferably maintained in a range between 10 pounds (4.5 kg) and 60 pounds (27.2 kg) of total pressure, and more preferably is maintained in a range between 20 pounds (9.1 kg) and 45 pounds (20.4 kg) of total pressure. The preferable pressure may also be defined as approximately 2.2 to 5.0 pounds per lineal inch, depending on the desired pressure parameters. However, the pressure may be substantially lower or higher than this range, depending on the other selected parameters of a particular desired nip area, including the rollers used, the liquid toner formulation, and the substrate onto which an image is applied. The rollers 12 and 16 may have different diameters from each other; however, the roller materials used and the pressures selected may be different than if the rollers were the same diameter. In such an embodiment, the rollers may rotate at different speeds from each other, where one or both of the rollers may be driven, depending on the roller configuration.

As described above, the arrow 26 of Figure 2 shows the direction the substrate 24 is moving in this embodiment. To facilitate such movement of the substrate 24, the rollers 12

and 16 rotate in the directions shown by arrows 34 and 40, respectively. One or both of these rollers 12, 16 may be driven by a driving mechanism (not shown) of any type capable of providing the desired movement of the substrate 24 through the system 10. A liquid toned image may be provided on at least one of an upper surface 20 and a lower surface 22 of substrate 24 when that substrate 24 is fed into the nip 32. The roller that faces the image or images, whether it is roller 12, roller 16, or both rollers 12 and 16 if the image is printed on both sides of the substrate 24, should be heated to provide a temperature in the nip area 32 that will preferably allow at least a portion of the carrier liquid to evaporate and will more preferably cause a substantial portion of the liquid to evaporate.

When a toned image is provided on a single surface of the substrate 24, it is preferred that the toned image faces upwardly or substantially upwardly, because the carrier liquid will typically rise and move away from the substrate 24 as it evaporates. For example, in this preferred embodiment, the image would preferably face roller 12. If the toned image is facing downwardly (in this case, toward the roller 16), the rising evaporated carrier may be at least partially reabsorbed into the substrate 24 or image or trapped underneath the substrate 24, where it might condense. However, a substrate provided with a toned image facing down (e.g., toward the roller 16) is considered to be within the scope of the present invention, although the amount of toner evaporation may differ from those situations where the image is facing upwardly. In these situations, the size of the nip area and the temperature of the rollers may need to be adjusted accordingly. Thus, if the toned image is facing down in a system such as that shown in Figure 2, various parameters of the system (e.g., temperature, pressure, etc.) may be adjusted to different levels than when the toned image is facing up in the system in order to achieve the same amount of carrier liquid evaporation.

In order to heat the rollers 12 and/or 16 to a desired temperature, a variety of heating methods and devices may be used. One example of a heating element that can be used to heat the various rolls of the present invention is a quartz halogen lamp, although other known means may be used to keep the rollers evenly heated. Halogen lamps provide certain advantages because they heat quickly and evenly, become very hot, and have a relatively long life. They can also be situated within a hollow core of a roller without

requiring contact with the roller itself, which is a feature that may help reduce the chance of mechanical failure associated with a loss of contact. In the embodiment of Figure 2, for example, rollers 12 and 16 are provided with internal heating elements 4 and 36, respectively, which may be halogen lamps or other heat sources. When such internal heating sources are used, the rollers 12 and 16 may include metal cores coated with heat-resistant rubber and a very low surface energy coating, such as silicone.

Another parameter that can be adjusted and controlled to achieve a certain amount of liquid carrier evaporation is the temperature of the rollers 12 and 16. In a preferred embodiment, roller 12 is heated to a temperature needed to evaporate the carrier. In such an embodiment, roller 16 may be heated to the same temperature as the roller 12 or to a lower temperature than the roller 12, or roller 16 may not have its own source of heating. It is the primary function of roller 12 in this embodiment to evaporate carrier liquid from a toned image on a substrate. It is a primary function of roller 16 to provide a rigid backup support for the substrate as it is being prefused, and subsequently, fused. However, either one or both of these rollers 12 and 16 can be heated as necessary to provide a relatively constant amount of heat to the substrate 24. In situations where only a small amount of heat needs to be transferred to the substrate for carrier liquid evaporation, for example, only one of the rollers 12, 16 may need to be heated, or it may be possible for both rollers 12, 16 to be heated to a relatively low temperature to achieve the same level of evaporation. Because the process of evaporation may tend to cool one or both of the rollers during the pre-fusing or evaporation step, one or both of the rollers 12, 16 may be provided with a feedback system to regularly monitor and adjust the amount of heat provided by the heat source or sources to maintain the temperature of the rollers within a desired range. Although the preferable temperature of the prefusing roller(s) is determined primarily by the liquid toner characteristics, the vaporization point of the chosen carrier liquid, and the fuser roller coating parameters, one preferred temperature range for the rollers 12 and/or 16 is between about 100°C and 150°C, with a more preferable temperature range of the rollers being maintained between about 110°C and 130°C.

The fusing apparatus or system of Figure 2 further includes a fixation or fusing step accomplished in a second fusing area with the roller 14 positioned to form a nip 42 with

roller 16. The fixation or fusing roller 14, in combination with roller 16, is placed to contact substrate 24 at some point after heat from the first nip 32 has heated the substrate 24 and caused at least a portion of the carrier liquid to evaporate. Again, the arrow 26 shows the direction of movement of the substrate 24, which also shows the direction the substrate moves toward the fusing roller 14 and nip area 42. The spacing or gap between the roller 12 and the roller 14 is preferably as small as possible to help to minimize the amount of fusing space required in the printing unit. However, it may also be desirable to provide at least a certain predetermined distance between the rollers 12 and 14, such as to keep the heat from one roller from affecting the heat provided by the other roller.

Once the substrate 24 has at least partially passed through the nip 32, it is conveyed to move forward, then pass into the fusing or fixation nip 42 between the rollers 14 and 16. To facilitate such movement of the substrate 24, the rollers 14 and 16 rotate in the directions shown by arrows 38 and 40, respectively. The roller 14 within a particular system 10 may be the same or different from the rollers 12, 16 used in the prefusing step, in durometer, rubber/coating thicknesses, and/or other parameters. Because the various toned images and the substrates on which they are to be fused can vary widely, the features and positioning of the rollers 14, 16 can also include many different characteristics and spacings relative to each other in the same way that the rollers 12, 16 can include a wide variety of characteristics and spacings relative to each other. Thus, the various alternatives and considerations described above relative to the rollers 12, 16 are applicable to the relationship between rollers 14, 16. However, because the roller 16 is common to more than one heating or fusing step (i.e., the roller 16 is part of both nip area 32 and nip area 42), consideration of the desired temperatures, pressures, and other parameters of both nip areas 32, 42 should be considered. For example, the temperature of the roller 16 should not be too high to achieve desired temperature characteristics in the first nip area 32, but should also not be too low to achieve desired temperature characteristics in the second nip area 42.

The roller pair 14, 16 preferably heat the toner particles to a temperature above their glass transition temperature (T_g) relatively quickly to provide the desired final fusion of toner particles to the substrate 24. Because the T_g of liquid toners will vary, the

temperature needed to reach this point will also vary, respectively. Thus, nip 42 at the second fusing step is usually maintained at a higher temperature than the nip 32, which is mainly designed to provide carrier liquid evaporation so that the substrate reaches the fusing step with a relatively dry toned image (i.e., relatively free of solvent). In order to maintain these relatively high temperatures, it is therefore preferable that both of the rollers 14, 16 are provided with a heat source, although it is possible that only one of the rollers has its own heat source. In the embodiment of Figure 2, for example, rollers 14 and 16 are provided with internal heating elements 44 and 36, respectively, which may be halogen lamps or other heat sources, such as are described above for the heat sources 4 and 36.

One preferred range of fusing temperatures for the nip area 42 between the rollers 14, 16 is between 130°C and 220°C; however, some liquid toners are more preferably fused at a temperature above 150°C. The fusing temperature is preferably not so high that it causes "offset" or transfer of the image to either of the fusing rollers. The fusing roller 14 may therefore be manufactured with the same core and material layers as the rollers 12 and 16 (discussed above); however, a release layer can be included on the fixation roller 14 that has a relatively high surface energy, where such release layer may be provided in the form of a molded sleeve formed from a fluorinated polymer, for example. Thus, because the image has been partially fused and a considerable portion of the carrier liquid will have been evaporated by the time the substrate reaches the nip area 42, the fusing roller 14 may include materials that can withstand higher temperatures than the materials used on the prefusing roller 12, such as sleeves or coatings available under the trade name "Teflon". In one exemplary embodiment of the present invention, the thickness of a coating layer on the fixation roller 14 can be about 0.025 mm to 0.050 mm, and the total diameter of the rollers can be about 35 mm with a Shore A hardness between 10 and 30. Further with regard to this exemplary embodiment, the rollers 14 and 16 preferably have a pressure applied between them of between 10 pounds (4.5 kg) and 60 pounds (27.2 kg) to create a nip 42 in a range of 1 mm to 3 mm, and more preferably is maintained in a range between 20 pounds (9.1 kg) and 45 pounds (20.4 kg) of pressure. As with the rollers in the prefusing step, the pressure may also be defined as approximately 2.2 to 5.0 pounds per lineal inch.

In one preferred embodiment of the present invention, the backup or compression roller 16 has a Shore A hardness of about 10. The backup roller 16 is supplied with an internal heating element 36 that is maintained at approximately the same temperature as the temperature of the prefusing roller 12. The prefusing roller 12 has a Shore A hardness of about 20-30 and is coated with a polydimethyl siloxane as a low surface energy release coating that is also absorptive, which provides enhanced lubricity and release characteristics. The two rollers 12, 16 are held together at a total force of about 45 pounds (20.4 kg) of pressure at nip area 32, which is preferably maintained at a temperature of about 100°C to 150°C. The fixation roller 14 is also configured to contact backup roller 16 with about 45 pounds (20.4 kg) of force at nip area 42. Roller 14 is covered with a release sleeve made from a fluorinated polymer that is able to withstand higher temperatures in the range of about 130°C-220°C. The nip 42 is thus preferably maintained at a higher temperature than roller 16 due to the higher temperature supplied by roller 14.

In one preferred embodiment of the present invention, the diameter of all of the rollers 12, 14, and 16 is approximately 35 mm, but this size is primarily chosen to accommodate the size of the electrophotographic apparatus. The rollers may be the same or different sizes than each other. A lower limit on roller diameter may be constrained at least by the need for rigidity of the rollers and sometimes by the need for a hollow space inside in which to insert heating elements while maintaining sufficient structural strength for the rollers. A lower limit on the diameter of roller 16 may also be constrained by the need to have two nips 32, 42 that are spaced relatively near to each other.

Because the substrate 24 passes through two nips 32, 42 sequentially, it is preferable to maintain a constant velocity of the rollers 12, 14, 16 to prevent wrinkling, tearing, or other damage to the substrate 24. There are several ways to drive the rollers, such as by driving the cores of the rollers 12, 14, and/or 16 with gears or attached motors. Another way is shown in the embodiment of Figure 3, as apparatus 200, which shows the addition of drive rollers 207, 209, and 211 to the embodiment of Figure 2, with a substrate 203 moving in a direction 205 through a prefusing nip formed by rollers 213 and 217, and then a fusing nip formed by rollers 215 and 217. In particular, drive roller 211 contacts the surface of roller 217 to rotate this roller 217 in a direction that is opposite that of the

drive roller 211 (as shown by arrows 219, 225). Further, the drive roller 207 similarly contacts the surface of roller 213 to rotate this roller 213 in a direction that is opposite the rotation of drive roller 207 (as shown by arrows 223, 227). Still further, the drive roller 209 similarly contacts the surface of roller 215 to rotate this roller 215 in a direction that is opposite the rotation of drive roller 209 (as shown by arrows 221, 229) In this embodiment, drive rollers 207, 209, and 211 can be engaged by either individual motors or drive systems, or can be driven by the same motor or drive system (not shown).

In addition, Figure 3 illustrates an additional optional feature of a system of the present invention that is particularly designed to help maintain the flatness of the substrate 24 as it moves between the two nips. In particular, one or more guides, such as the one shown schematically as guide 201, may be provided to keep the substrate from curling or bending after being exposed to heat in the prefusing step. The guide 201 may take any number of forms that do not damage the toned image or interfere with the movement of the substrate, but prevent or minimize folding or mutilation of the substrate as it enters the nip area. While these guides are illustrated in the embodiment of Figure 3, such guides may be used in any other embodiments of the present invention, such as the embodiment shown in Figure 2.

It is important that a fuser unit containing systems of the type shown in Figures 2 and 3 maintain adequate airflow to allow evaporated solvent and excess heat to escape. Evaporated solvent that is trapped in the fuser unit can re-condense or become re-absorbed into the final substrate or image, thereby destroying image quality. For this reason, the apparatus should preferably have an adequately open construction that allows solvent to escape. Additionally, a fan or other air movement device can be positioned to draw evaporated solvent from the area and/or to cool at least one of the rollers or the substrate, such as to help maintain the rollers and substrate within a preferred temperature range.

The embodiments of the present invention described above include two fusing nip areas, with the first or prefusing area preferably including a prefusing roller that is held at a lower temperature than the final fusing roller of the second or final fusing area. It is understood, however, that the first area may instead have a roller that is held to a higher temperature than the roller of the second area, or that both the prefusing and fusing rollers

are held at the same or very similar temperatures to each other. Further, a fusing system of the present invention may include more than two fusing stations, where stations that are intermediate to the initial and final fusing stations may each include additional fusing rollers that are provided at different or similar temperatures to the rollers of the other fusing stations. Because the additional fusing stations will necessarily require more processing space, however, it will typically be desirable to limit the number of fusing stations as much as possible to limit the overall size of the machines or apparatuses.

The operation of the present invention will be further described with regard to the following detailed examples. These examples are offered to further illustrate the various specific and preferred embodiments and techniques. It should be understood, however, that many variations and modifications may be made while remaining within the scope of the present invention. The fusing apparatus system arrangements used and tests conducted were as follows:

THE EXAMPLES

The apparatus was designed to meet the following specifications.

The fusing and prefusing rollers in the apparatus were 35 mm diameter rollers made of a metal core, a silicone rubber (or urethane rubber) base layer of 1-2 mm, and a release coating layer of polydimethyl siloxane or a fluorinated polymer over the base layer that was 0.025 mm to 0.050 mm thick. The durometer of the base and coating layers together was between 10 and 30 Shore A hardness. The rollers were hollow, with the insides painted with black "inside diameter" paint to aid in thermal conductivity, and heated from the inside by halogen lamps. The prefusing roller was maintained at about 130°C and the fixation roller was maintained at about 180°C.

The prefusing roller was coated with an absorbent polydimethyl siloxane formulation to assist in surface lubricity. The fixation roller was fitted at the manufacturer with a durable molded fluorinated polymer sleeve (known as PFA).

The backup or compression roller was not coated with any rubber or release material, but if a substrate was provided with images on both sides, it was preferred that a rubber and/or release coating also be provided on the backup roller. The backup roller

also had a hollow core similar to that described above, in which a halogen heating lamp was also inserted. The backup roller was heated to about 130°C.

The prefusing and fusing rollers were situated against the backup roller with about 45 pounds of total applied force on each roller. The prefusing and fusing rollers were spaced less than about 5 cm from each other.

Tests were run using both a single-roller fusing system designed for dry toner fusing, and using the dual roller fuser. The results are shown in the table and discussed below.

Test Methods and Apparatus

In the practice of the invention, the following test methods were used to determine the quality of printing transferred to a substrate:

Erasure resistance:

In order to quantify the resistance of the printed ink to erasure forces after fusing, an erasure test has been defined. This erasure test consists of using a device called a Crockmeter to abrade the inked and fused areas with a linen cloth loaded against the ink with a known and controlled force. When the linen cloth has been fixtured onto the Crockmeter probe, the probe is placed onto the inked surface with a controlled force and caused to slew back and forth on the inked surface a prescribed number of times (in this case, 5 times by the turning of a small crank with 5 full turns at two slews per turn). The inked test area was long enough so that during the slewing, the erase head never left the inked surface by crossing the ink boundary and slewing onto the paper surface.

The Crockmeter used in this testing was an AATCC Crockmeter Model CM1 manufactured by Atlas Electric Devices Company, Chicago, IL 60613. The head weight of this device was 934 grams, which is the weight placed on the ink during the 5-slew test, and the area of contact of the linen cloth with the ink was 1.76 cm^2. The result of this test is a ratio of measurements of the density of ink on the linen abrading cloth after 5 slews on the printed ink test sample at the applied force per unit area of 530g/cm^2 to the original density of the ink on the paper before testing. In order to pass this erasure test,

the density of the erased (test) area must be at least 95% of its original density. Otherwise, the process will be judged to fail and will be designated to have inadequate erasure resistance. The actual calculation is as follows:

$$\text{ERASURE} = (OD_{print} - OD_{cloth}) / (OD_{print}) \times 100\%,$$

where OD_{print} is the original optical density of ink on the print or substrate and OD_{cloth} is the optical density of ink on the abrading cloth after the 5 slew test.

These tests are conducted frequently on random printed and fused images to ascertain consistency in image durability and were used with the following invention to benchmark success or failure of the embodiments with various liquid toner formulations.

Offset

Offset occurs when part of the toned image on the substrate is transferred from the substrate to a fusing roller. There are two types of offset. Cold offset occurs when the fusing rollers are not hot enough to evaporate the solvent and change the rheology of the toner so that it will fuse to the substrate. Hot offset occurs when the fusing rollers are too hot and the toner is melted, but comes off on the fusing roller. In either case, the image is damaged and will not achieve a rating of 0 (no offset), which is the only acceptable rating in the printing industry. Following are the ratings and definitions thereof used in this analysis:

Offset ratings:

0= no offset,

1= very slight, rare,

2= occasionally noticeable (every 10-12 pages),

3= noticeable (every 4-5 pages),

4= noticeable most of the time, toner is redeposited on the substrate downstream from where it was removed,

5= large pieces of image offset constantly, continuous re-depositing of toner image downstream on substrate.

The following results were obtained from a fusing device configured like the one seen in Figure 1 (prior art) made for dry toner fusing applications. They are demonstrative of the problems faced when trying to fuse liquid electrophotographic toners. That is, using a fusing system designed for dry toner fusing processes, there is no apparent solution space for prints that have both adequate erasure resistance and no offset.

Single-station (one roller pair) fusing

Type of Roller coating used	Roller temperature	Erasure Resistance	Offset
Rubber roller from Bando with a highly absorptive polydimethyl siloxane coating Shore A hardness 10	75°C	No data	Cold offset: 5
	100°C-110°C	85%	Hot offset:1
	120°C-130°C	95%	Hot offset:3
	145°C-160°C	97%	Hot offset: 4

Double station (two roller pairs) fusing

In accordance with the practice of this invention, such as the system 10 shown in Figure 2, the two rollers used for this testing included: Roller 1, (the prefusing roller) having a high absorbancy polydimethyl siloxane coating (for low surface energy and a low cold offset temperature), and Roller 2, (the fusing or fixation roller) having a Teflon® sleeve over the rubber (to provide for low surface energy and a high hot offset temperature). These sleeves are also very durable for long periods of time at the relatively high temperatures needed to adequately fuse an image.

Roller(s) used	Roller temperatures	Erasure Resistance	Offset
Roller 1	95°C	77%	0
Roller 2	180°C	90%	5
Roller 1/Roller 2	90°C/180°C	98%	1.5
Roller 1/Roller 2	95°C/180°C	98%	0
Roller 2/Roller 2	50°C/180°C	90%	0

From this data and the observations of the tests performed, it was observed that the first roller evaporated and/or absorbed the majority of the carrier liquid, which allowed the second roller to adequately fuse the image without offset. This was accomplished by careful selection of coating/release materials. For example, the performance of the system was better, even at cooler temperatures, when the prefusing roller had a coating with a low surface energy and that was at least somewhat absorbent (so that at least some of the carrier liquid that absorbed into the coating layer could provide lubrication and release properties), and when the fixation roller had a coating that was durable and able to withstand high heat for long periods of time without substantially changing surface energy characteristics.

The present invention has now been described with reference to several embodiments thereof. The entire disclosure of any patent or patent application identified herein is hereby incorporated by reference. The foregoing detailed description and examples have been given for clarity of understanding only. No unnecessary limitations are to be understood therefrom. It will be apparent to those skilled in the art that many changes can be made in the embodiments described without departing from the scope of the invention. Thus, the scope of the present invention should not be limited to the structures described herein, but only by the structures described by the language of the claims and the equivalents of those structures.